Preon Trinity - a new model of leptons and quarks [1]

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Abstract. A new model for the substructure of quarks, leptons and weak gauge bosons is discussed. It is based on three fundamental and absolutely stable spin-1/2 preons. Its preon flavour $SU(3)$ symmetry leads to a prediction of nine quarks, nine leptons and nine heavy vector bosons. One of the quarks has charge $-4e/3$, and is speculated to be the top quark (whose charge has not been measured). The flavour symmetry leads to three conserved lepton numbers in all known weak processes, except for some neutrinos, which might either oscillate or decay. There is also a (Cabibbo) mixing of the d and s quarks due to an internal preon-antipreon annihilation channel. An identical channel exists inside the composite Z^0, leading to a relation between the Cabibbo and Weinberg mixing angles.

1. Introduction

In this talk I will present a new preon model where leptons, quarks and heavy vector bosons are composite objects with a fairly simple inner struc-

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ture. It is the result of a collaboration between the universities of Clermont-Ferrand, Torino and Luleå within an EU-sponsored network, where also groups from Paris and Thessaloniki are involved in other projects.

Our inspiration has come from a certain fatigue with the standard model and its rather complicated Higgs mechanism, but also from its phenomenological success, which has convinced us that "there is something more fundamental behind". Let me therefore start by giving our favourite preon arguments, and first two of a more general nature:

Why not?
It should be fully natural to speculate about compositeness, especially as it is impossible to prove, by any means, that a particle is *not* composite! So, why not composite preons? Well, pre-preons already exist (...in the literature).

There is always a deeper layer...
History tells us that whenever a model of matter has become more and more complicated without providing a deeper understanding, another layer of fundamental particles has been suggested - and found. But another lesson of history is that a vast majority of all researchers have treated the currently known fundamental particles as *the* ultimate level, until the facts have been obvious!

Among the more detailed arguments, we would like to list the following (many of which, but not all, have been discussed before [1]):

(i) There are by now "too many" leptons and quarks. It is a puzzle why God the Almighty would prefer twelve fundamental particles. The only reason I can find is that he chose one per Apostle, but that would restrict the standard model to Christianity, which seems a too limited scope. *Three* is a more universally sacred number.

(ii) There is a pattern among the six leptons and six quarks, *i.e.*, the family structure. Historically, such patterns have led to ideas about compositeness, with the quark model as a typical example.

(iii) The mathematically least attractive features of the standard model come from the fact that the weak interaction has gauge bosons that are massive (as well as unstable and of different charges). In preon models, they can be seen as composite states. The weak interaction is a "leakage" of multi-preon states, in analogy to the nuclear force being mediated by quark-antiquark states. If so, there is no fundamental electroweak unification and no need for the Higgs mechanism (nor for multi-Higgs, higgsinos or composite Higgs).

(iv) An overlooked hint is that most quarks and leptons are *unstable*, which in our view disqualifies them as fundamental particles. Historically,

all decays of "elementary" particles have sooner or later been interpreted in terms of more fundamental objects.

(v) There are mixings, transitions, or oscillations among some of the "fundamental" particles, such as among some quarks, and also among neutrinos. This reminds about the mixing of K_0 and $\bar{K}_0$, now being understood in terms of quarks.

(vi) There are conserved quantum numbers such as lepton numbers and weak isospin, which we do not understand. When isospin and strangeness were introduced in particle physics, the explanation turned out to be in terms of quarks and (partly) conserved quark flavours. One of the visions for any preon model should be to reduce the flora of *ad hoc* quantum numbers.

2. General preon considerations

Preon models have so far focused on explaining the lightest family of two quarks (u and d) and two leptons (e and ν_e) with as few preons as possible. This means either a minimal number of (two) different preons, *e.g.*, the "rishons" [2, 3], or a minimal number of (two) preons inside a quark or lepton, *e.g.*, the "haplons" [4].

The two heavier families are either considered "excitations" of the light one, or prescribed to have a completely different internal structure, *e.g.*, with different numbers of preons inside different quarks. As a result, no simple, consistent and predictive preon model exists. Neither have preon models been able to explain the cornerstones of the standard model from preon properties. Rather, lepton number conservation, the Cabibbo-Kobayashi-Maskawa (CKM) mixings [5], and the similarities between leptons and quarks, have either been left unexplained, or implemented on the preon level.

Nevertheless, we have been much inspired by the work of others, when formulating our model. In particular, we would like to mention that we have stolen, and customised, the following ideas:

(i) the idea from the original $SU(3)$ quark model by Gell-Mann and Zweig [6] that all hadrons known in the early 1960s can be explained in terms of only three light quarks, with a (broken) flavour-$SU(3)$ symmetry;

(ii) the idea from the rishon model that members of the lightest family have three preons each;

(iii) the idea from the haplon model that the members of the lightest family can be built by one spin-1/2 and one spin-0 object;

(iv) the idea of diquark models [7] that quarks like to pair-up in tightly bound spin-0 systems;

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Table 1. Our "supersymmetric" preon scheme.

charge	$+e/3$	$-2e/3$	$+e/3$
spin-1/2 preons	α	β	δ
spin-0 (anti)dipreons	$(\bar{\beta}\bar{\delta})$	$(\bar{\alpha}\bar{\delta})$	$(\bar{\alpha}\bar{\beta})$

(v) the idea of supersymmetry that spin-1/2 objects have relatives with spin 0, even if only in a phenomenological sense, such as the "supersymmetry" between quarks and diquarks in mesons and baryons [7].

3. A trinity of preons

A preon model for six leptons and six quarks must have at least five different preons in the sense of the haplon model, *i.e.*, three with spin 1/2 and two with spin 0, or *vice versa*. In order to get a more symmetric scheme it seems reasonable to have three of each, giving nine leptons and nine quarks.

The spin-1/2 and spin-0 preons can be given pairwise identical charges, which by "accident" are those of the three lightest quarks. In order to bring down the number of preons, we suggest that the spin-0 ones are not fundamental, but tightly bound "dipreon" pairs of the spin-1/2 preons. Calling the preons α, β and δ, and giving them charges $+e/3$, $-2e/3$ and $+e/3$ (for simplicity; there is an ambiguity between the names preon and antipreon), we get the simple and symmetric scheme in Table 1. Each preon has a partner, which is the dipreon formed by the other two (anti)preons.

This model leads to a surprisingly rich spectrum of predictions and explanations connected to the standard model. But before building up leptons, quarks and vector bosons by combining preons with dipreons and/or their anti-particles, we list the properties of the preons themselves.

(i) *Mass*: In order to understand why only six leptons, six quarks and three vector bosons have been seen, it is tempting to speculate that one of the preons is superheavy, say the δ. The α and β are much lighter. The "heaviness" of the δ preon hence plays the role of strangeness in the quark model. It should be noted though, that the more bound a fundamental particle is, the less precise is the definition of its mass. An illustrative paradox is that dipreons containing the δ do not seem to be superheavy.

(ii) *Spin and electric charge*: These are just implemented on the preon level. It might be worthwhile here to contemplate the fundamental differ-

ence between the α and δ preons. Maybe this is in terms of a different magnetic charge, coupled to both electric charge and spin.

(iii) *QCD colour*: It is necessary to assume that all preons are colour-$\mathbf{3}^*$ in normal QCD, in order to understand why leptons and vector bosons are colour singlets and quarks colour triplets. The assignment $\mathbf{3}^*$ instead of $\mathbf{3}$ is again a technicality because of our definition of preons *vs.* antipreons. Then also the (anti)dipreons in Table 1 are $\mathbf{3}^*$ ($\mathbf{3} \otimes \mathbf{3} = \mathbf{3}^* \oplus \mathbf{6}$).

(iv) *Preon flavour*: The preon flavour plays, at first sight, the same role in this model as the quark flavours did in the original quark model, *i.e.*, the model has an approximate flavour-$SU(3)$ symmetry. It cannot be exact for masses and wave functions, but unlike the quark model, we suggest that the net flavours are exactly conserved in nature, as a consequence of the next point. Note that the preons are flavour-$\mathbf{3}$, the dipreons $\mathbf{3}^*$, and the antidipreons $\mathbf{3}$.

(v) *Absolute stability!*: Unlike the situation for "fundamental" particles in the conventional standard model, we assume that preons are absolutely stable against decay. All weak decays in nature are therefore consequences of a mere reshuffling of preons into particles with a lower total rest mass.

(vi) *"Hypercolour"?*: Most preon models rely on some new, superstrong force that keeps leptons and quarks together. Assuming that it is QCD like, it is usually called hyper-QCD or super-QCD, with hyper-gluons etc. There are also suggestions that it might not be $SU(3)$ symmetric, but obey some more complicated group theory, such as $SU(4)$.

It is noteworthy that *no* other preon quantum properties are needed in order to understand all quantum numbers of leptons and quark. So, there is no lepton number, no baryon number, no isospin, strangeness or weak isospin on the preon level.

4. The leptons

Leptons are assumed to be three-preon states, in the form of a preon and a dipreon, all in colour-singlet ($\mathbf{3}^* \otimes \mathbf{3} = \mathbf{1} \oplus \mathbf{8}$). We assume that colour-octet leptons do not exist. The lepton scheme that we favour is given in Table 2.

Note that this matrix is set up as a rough scheme, without a deeper consideration of what the actual preon wave functions would be, *i.e.*, quantum-mechanical mixings of the simple products of single-preon wave functions. We will turn back to such questions later. Next we discuss the lepton properties, point by point.

(i) All leptons are correctly reproduced with all their quantum numbers (except, possibly, helicity, since it is not obvious from the scheme why neutrinos are left-handed and antineutrinos right-handed). There is an ambiguity in the scheme, since it would work equally well with the "electron"

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Table **2.** Leptons as three-preon states.

	$(\beta\delta)$	$(\alpha\delta)$	$(\alpha\beta)$
α	ν_e	μ^+	ν_τ
β	e^-	$\bar{\nu}_\mu$	τ^-
δ	$\bar{\nu}_{\kappa 1}$	κ^+	$\bar{\nu}_{\kappa 2}$

column interchanged with the "τ" column. We will discuss this ambiguity later.

(ii) There are three new (superheavy) leptons, all containing an "isolated" δ preon. Two of these are neutrinos, which must be heavier than half the Z^0 mass, in order not to violate the finding that there are only three light neutrinos. These neutrinos must naturally be unstable.

(iii) There is no subscheme in terms of three lepton families. The only mathematical structure is the one given by preon-flavour $SU(3)$, which splits up the nonet in one octet and one singlet, exactly like with the three-quark baryon octet ($\mathbf{3}\otimes\mathbf{3}^* = \mathbf{8}\oplus\mathbf{1}$). When constructing true flavour-$SU(3)$ based wave functions the singlet is to be found as a linear combination of the three neutrino cells on the main diagonal, while the other two combinations are the lepton equivalents of the baryons Σ^0 and Λ^0 in the quark model.

(iv) The basic scheme contains the electron and the *anti*muon on equal footing, and similarly for their neutrinos. This whets the appetite for speculations that helicity has to do with the properties of the "naked" preon outside the spin-0 dipreon.

(v) There is no simple mass-ordering in the scheme, which makes it a much tougher challenge to find mass-formulas and a dynamics, than in the quark model. One trend is that the mass increases along all diagonal lines from upper left to lower right.

(vi) The three traditional lepton numbers are conserved in all well-established processes. This mirrors the conservation of preon flavour. As to the best of our knowledge, this is the only preon model that links the lepton numbers, and the virtual three-family structure, to a more fundamental concept. Muon decay, $\mu^- \to \nu_\mu + e^- + \bar{\nu}_e$, is a typical example: $\bar{\alpha}(\bar{\alpha}\bar{\delta}) \to \bar{\beta}(\bar{\alpha}\bar{\delta}) + \beta(\beta\delta) + \bar{\alpha}(\bar{\beta}\bar{\delta})$. The dipreon goes into the muon neutrino, while the preon hides inside a $W^- = \beta\bar{\alpha}$, which then decays into the electron and its neutrino. All efforts to violate lepton number conservation by splitting up the leptons differently lead to final states that violate energy conservation.

(vii) There is no general lepton number conservation! First of all, there

is no fourth lepton number connected to the superheavy κ and its two neutrinos. Rather, their decays *must* violate also the normal lepton numbers, an illustrative example being: $\kappa^+ \to \mu^+ + \nu_e + \bar{\nu}_\tau$.

(viii) An attractive aspect of the lack of a general lepton number conservation is that the three neutrinos, ν_e, $\bar{\nu}_\mu$ and $\bar{\nu}_{\kappa 2}$ along the main diagonal can mix quantum-mechanically, because they have identical preon contents, differing only in the internal spin composition: $\nu_e = \alpha(\beta\delta)$, $\bar{\nu}_\mu = \beta(\alpha\delta)$ and $\bar{\nu}_{\kappa 2} = \delta(\alpha\beta)$. This brings up the issue of the ambiguity between the left-most and right-most columns in Table 2, since a shift of columns would involve the ν_τ in the mixing, instead of the ν_e. A three-neutrino mixing might induce neutrino oscillations, $\nu_e \leftrightarrow \bar{\nu}_\mu \leftrightarrow \bar{\nu}_{\kappa 2}$. But there could also be decays, like the electromagnetic $\bar{\nu}_\mu \to \nu_e + \gamma$, or the more exotic $\bar{\nu}_\mu \to \nu_e + \phi$, where ϕ is a light scalar, such as a Goldstone boson, or a bound scalar preon-antipreon state, say $(\alpha\bar{\alpha})$. The photon decay has been studied recently by one of us within the same formalism as the quark analogy $\Sigma^0 \to \Lambda^0 + \gamma$ [8], but no conclusion can be drawn about the neutrino lifetime or the photon spectrum. Finally, it should be noted that it is the *anti*muon neutrino that mixes with the electron (or tau) neutrino. This is not obviously forbidden by helicity conservation, since massive neutrinos have both left-handed and right-handed components. One can also think of helicity-conserving oscillations, where the neutrino appearing with the wrong helicity is sterile. Such sterile neutrinos are often needed in ambitious efforts to fit all neutrino data in terms of oscillations.

(ix) A final, but important point, is that the lack of lepton number conservation cannot, in our scheme, allow for mixings of the *charged* leptons. Such mixings can occur *only* if there is a more basic, quantum-mechanical ("Cabibbo") mixing of the α and δ preons inside leptons and quarks. That would violate the exact conservation of three preon flavours, but cannot be excluded, on the *per mille* level, by the experimental data. We will discuss this issue again in connection to quarks.

5. The quarks

In a similar spirit as with the leptons, we now construct, in Table 3, the quarks as bound states of a preon and an antidipreon in colour triplet $(\mathbf{3}^* \otimes \mathbf{3}^* = \mathbf{3} \oplus \mathbf{6}^*)$. Again, the contents of the cells are not meant to give the exact preon wave functions of the quarks.

The following list of quark properties takes up several new features that do not appear for leptons.

(i) All known quarks are correctly reproduced. There is no overall ambiguity in the scheme.

Table 3. Quarks as preon-antidipreon states.

	$(\bar{\beta}\bar{\delta})$	$(\bar{\alpha}\bar{\delta})$	$(\bar{\alpha}\bar{\beta})$
α	u	s	c
β	d	X	b
δ	$t?$	g	h

(ii) There are three new quarks, but these are not obviously the ones with an "isolated", superheavy δ preon. Two of them belong to this category, the g and h quarks (for "gross" and "heavy"), but the third (X) is on the second line, and not clearly superheavy.

(iii) On the other hand, the top quark is among the superheavies, which would explain why it is so much heavier than its conventionally assigned partners, the b quark and the τ lepton. This would also give some hope that "superheavy" in our model means around a few hundred GeV, which would make the CERN LHC ideal for discovering the remaining leptons, quarks and vector bosons. They might even be within reach of the Fermilab Tevatron.

(iv) The quarks have no three-family grouping either, but here the flavour-$SU(3)$ decomposition is into a sextet and an anti-triplet ($\mathbf{3} \otimes \mathbf{3} = \mathbf{6} \oplus \mathbf{3}^*$). The anti-triplet contains the three quarks on the main diagonal, while the other quarks form the sextet. Here it should be mentioned that a flavour-sextet assignment for quarks has been suggested also by Davidson *et al.* [9], and speculated to be a consequence of a preon substructure, although without reference to any particular preon model.

(v) The appearance of the X quark with charge $-4e/3$ opens up for some thrilling speculations. At first sight it should not be superheavy, since it does not have a naked δ. However, the X belongs to a flavour antitriplet together with the u and h, and different $SU(3)$ representations can have different mass formulas. Another idea is that a "light" X quark has escaped discovery. Searches for new quarks seem to focus on a "fourth-family" b' with charge $-e/3$ [10]. They rely on model-dependent assumptions on b' decay [11] in ways that would make the suggested decay of the X "invisible". Neither has there been searches for new resonances in e^+e^- collisions at high energies in the traditional way of fine-tuning the total energy in small steps. It is, however, unlikely that a light X would not have been detected in the search for the top quark [12]. The case for an X with a mass below, say, the W mass is therefore weak.

(vi) A final speculation about the X is that it is indeed identical to the

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discovered top quark. This idea cannot easily be dismissed, since there is no measurement of the top charge [12]. The top quark was found through its presumed main decay channels, namely semi-leptonic ones like $t \to b + \ell^+ + \nu$, or non-leptonic ones like $t \to b + u + \bar{d}$, where a few b quarks have been "tagged" by a charged muon in semi-leptonic decays. However, the situation is rather complex because a total event contains the decay of the full $t\bar{t}$ pair into several leptons and hadronic jets, and the identification and matching of those are non-trivial. The corresponding decay channels for the antiquark $\bar{X}$ would be $\bar{X} \to \bar{b} + \ell^+ + \nu$ and $\bar{X} \to \bar{b} + u + \bar{d}$, so that the full $X\bar{X}$ decay would give the same leptons and jets as in a $t\bar{t}$ decay, although with a different $b - W$ matching. A study along these lines [13] shows that only a couple of events give a weak support for the conventional charge, in the sense of χ^2 fits to different jet identifications, while the bulk of events are inconclusive. Hopefully, this issue will be settled soon at the upgraded Tevatron, thanks to better statistics and also better possibilities to study outgoing particles much closer to the interaction vertex. It is interesting to note that also Chang *et al.* [14] have suggested that the top charge is $-4e/3$, although within an analysis built on details of the standard model that do not appear in our preon model (*e.g.*, the Higgs mechanism).

(vii) Quark decays are mostly similar to lepton decays, since they normally mean a regrouping of preons. An example is beta decay: $d \to u + e^- + \bar{\nu}_e$, which is $\beta(\bar{\beta}\bar{\delta}) \to \alpha(\bar{\beta}\bar{\delta}) + \beta(\beta\delta) + \bar{\alpha}(\bar{\beta}\bar{\delta})$. However, some quarks have pairwise identical net preon flavour, just like the three neutrinos discussed earlier. The best example is the d and s quarks, having the flavour of the δ. This makes possible a quantum-mechanical mixing of the two quarks, and another type of transition between them, compared to normal quark decays. This is the preonic explanation of the Cabibbo mechanism. An $s \leftrightarrow d$ transition goes through annihilation channels like $\alpha\bar{\alpha} \leftrightarrow \beta\bar{\beta}$ involving the "naked" preon and the corresponding antipreon inside the dipreon. No such channels exist for leptons, but as we will see below, they are important also inside the preon-antipreon Z^0. In terms of wave functions and the notions of the Cabibbo theory, the d and s quarks are the flavour-$SU(3)$ eigenstates produced in preon processes, while the mass eigenstates, d' and s', relevant for weak decays, are mixtures of these preon states, parametrised by the Cabibbo angle. As the Cabibbo mechanism is just put in "by hand" in the standard model, we regard this connection between the preon substructure and the mixing of d and s one of the most promising features of our model.

(viii) The smaller elements of the CKM matrix cannot be accounted for by such preon annihilation channels, although it is noteworthy that they are much smaller than the Cabibbo mixing, and hence might have a different explanation. We point out that such effects can result from a

Table 4. Vector bosons as preon-antipreon states.

	$\bar{\alpha}$	$\bar{\beta}$	$\bar{\delta}$
α	Z, Z'	W^+	Z'''
β	W^-	Z', Z	W'^-
δ	Z'''	W'^+	Z''

very small quantum-mechanical mixing of the α and δ preons inside the quark (and lepton) wave functions. This would mean that flavour-$SU(3)$ is heavily broken on the mass level (quark and lepton masses), somewhat broken in wave functions (Cabibbo mixing), and just a little broken on the quantum-number level (*i.e.*, preon flavour is not exactly conserved). Again, the situation is principally very similar to the early quark model.

6. The heavy vector bosons

The vector bosons are preon-antipreon states, as in several other preon models. In our model there will be nine of them, as in Table 4.

The following observations can be made.

(i) This nonet is very similar to the vector mesons in the quark model $(\rho, \omega, \phi, K^*)$. Some examples are: Both carry a "leakage force", the weak and nuclear ones; both Z^0 and ρ^0 are heavier than their charged counterparts (which is rare in particle physics); and both Z^0 and ρ^0 are believed to mix with the photon, as described by the electroweak theory and the vector meson dominance model. In the meson case it is acknowledged that these phenomena are consequences of the quark structure, while for vector bosons they are just put in by hand in the standard model, but are due to preons in our model.

(ii) There are no known scalar counterparts to the vector bosons, although these are expected in many preon models [1]. It is not known if they are even heavier than the vector bosons, or have extremely weak couplings to other particles, or are very light, but hidden inside scalar mesons as Fock states. It is a crucial challenge to preon models to find these scalars.

(iii) The standard model concepts of weak isospin, Weinberg mixing etc appear in this model on the same level as the Cabibbo and neutrino mixings, *i.e.*, as consequences of (broken) flavour-$SU(3)$ on the preon level. In Table 4, the hypothetical particle normally called W^0 (the weak isotriplet)

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is the $SU(3)$ eigenstate $\alpha\bar{\alpha} - \beta\bar{\beta}$, while the isosinglet B^0 is $\alpha\bar{\alpha} + \beta\bar{\beta}$ (neglecting a possible admixture of the superheavy δ). The mass eigenstates, Z and Z', are mixtures of these, parametrised by the Weinberg angle. Note that the state orthogonal to Z is *not* the photon, as in the standard model, but the heavier Z'. This is more like the vector mesons, where the ω is the heavier partner of the ρ^0. The difference between the W^0 and B^0 components of Z can be seen through decays, where the latter mode gives access to preon-antipreon annihilation channels, identical to the ones inside quarks. This makes it extremely tempting to speculate about a possible relation between the Cabibbo angle for quarks and the Weinberg angle for Z decays. We have found such a simple relation, but there are so many ifs and buts in its proof that we will present it in a publication of its own.

7. Further challenges

Our model provides a qualitative understanding of several phenomena that are not normally analysed within preon models, nor within the standard model. It can hence serve as a basis for a deeper understanding of the quantitative success of the standard model.

However, many problems remain to be solved, and I will finish by listing some of them below.

(i) The model lacks a dynamical basis, which means that masses cannot yet be explained, the exact preon wave functions cannot be calculated, and the forces that keep leptons and quarks together are not understood. In this respect we are worse off than the original quark model, which at least rested on a phenomenologically successful mass formula for baryons.

(ii) There is no particular reason why quarks would be as fundamental as leptons in our model, or even exist as particles, since there is no obvious hyper-QCD theory that would make quarks "hyper-colour neutral", like leptons. The fundamental status of quarks must therefore be due to some more intricate dynamics.

(iii) It is not yet clear to us if *all* phenomenologically successful aspects of the electroweak theory can be explained by preons, not to mention CP violation. A lot of work remains to be done, maybe of the order of the total work so far devoted to the standard model, *i.e.*, a few thousand man-years!

(iv) The hints of a slightly broken preon flavour conservation reminds so much of the quark model that the mind goes to yet more preons, even unstable ones and in families, which would again call for a model with fewer, and more basic constituents, *i.e.*, pre-preons.

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Acknowledgements

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